[Proc. Roy. Soc. Victoria, **44** (N.S.), Pt. II., 1932.]

Art. XVI.—*The Distribution of the Zones of the Castlemaine and Darriwil Series near Ingliston.*

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(With Plate XX.)

[Read 10th December, 1931; issued separately 20th April, 1932.]

Introduction.

The area dealt with is about 3 miles S.-E. of Ingliston, which is a few miles west of Bacchus Marsh. It is, roughly, equivalent to the Ironbark Ranges, the rugged topography produced by the erosion of the Lower Ordovician being replaced to the north and west by the open country characteristic of granitic outcrops. South-east of Pyramid Rock, an abrupt change in the form of the Werribee Valley and in the type of country generally, occurs at the junction of the Ordovician and the Permo-Carboniferous. The Newer Basalt, with its associated Tertiary deposits, forms a plain, dissected by the Ironbark Creek, in the southern part of the area.

The Ordovician is the only system studied in detail, and in the present paper an attempt is made to deduce the structure of the area from the distribution of the various graptolite faunas of the black slates, applying the now well-established divisions of the Darriwil series. Observations of dip and strike were made at many points and the evidence from them taken in conjunction with that of the graptolites. The black slate outcrops shown on the map were located by means of compass and chain traverses on the road and railway section, and compass and pace traverses on the Ironbark Creek and Creeks B and C.

Previous Work.

The northern part of the area is shown on quarter-sheet No. 12 N.-E., and contours for this part, used in constructing the section, were obtained from the Military Survey Contour Map, Sheet South J55 G.III. IV.

An unpublished map on the scale of 4 inches to the mile, based on the work of Mr. H. Foster, for the use of which I am indebted to Mr. W. Baragwanath (Director of the Geological Survey of Victoria), shows in detail the black slate outcrops and graptolite localities of the southern half of the area.

It has long been well known that the graptolite faunas of the black slates were of Darriwilian age. Hall[1] recorded *Tetragraptus serra, Phyllograptus* sp., *Didymograptus caduceus, D.* sp. nov. (large form) from the railway cutting 42¾ miles from Melbourne. These forms enabled him to correlate the beds with the Castlemainian of Yapeen or Woodend. This report was written prior to the extension downwards of the Darriwil by W. J. Harris.[3]

In the course of descriptions of new graptolite species Hall[2] recorded *Oncograptus upsilon* from a quarry near the viaduct (42½ miles from Melbourne) on the railway, and Harris[4] similarly noted the occurrence of *Cardiograptus morsus* in the Ingliston district.

Nature of the Ordovician Sediments.

Graptolites are restricted to thin black slate bands which, however, are very persistent over the area. Sandstones are fairly common, but white to yellowish slates make up the bulk of the sediments. The slates are highly cleaved, and as bedding and cleavage are frequently inclined, it is difficult at some localities to obtain a representative fauna. For the same reason, in deducing the structure of the area, more weight is attached to the evidence of the graptolites, since at times in unfossiliferous localities the cleavage and dip are almost indistinguishable, and dip observations are therefore impracticable. This difficulty is absent in the centre of the area, where sufficient depth of exposure is obtained in the cuttings along the road and the railway.

Though most of the black slates examined are within the metamorphic aureole of the adamellite, the graptolites are usually well preserved if the slates are not too weathered. As the adamellite is approached, however, the slates become indurated and spotted, and develop a rough fracture, so that any graptolites preserved are difficult to obtain. Along the Werribee River, the original muds were probably slightly different in composition, and metamorphism produced phyllitic slates which are not conspicuously spotted. This lithological distinction has been used in fixing a tentative lower boundary for D2, since graptolites are rare in the critical locality.

Basis of Palaeontological Zoning.

The whole of the Ordovician in this area belongs to the Castlemaine and Darriwil series. The following scheme of subdivisions is based on that of Harris and Keble.[5] Slight additions, for example the passage beds between D5 and D4, appear; but as these are not recorded in other areas of Darriwilian age, they may be only of minor importance.

Series.	Zone.	Zonal Fossils.	Other Characteristic Fossils.
Darriwil ..	D2	*Diplograptus austrodentatus* H. and K. *Glossograptus* sp. (absence of *Cardiograptus morsus* H. and K.)	*Didymograptus caduceus* Salt. *D. v-deflexus* Harris *Trigonograptus*
	D3	*Cardiograptus morsus* (absence of *Oncograptus*)	*Didymograptus caduceus* *D. v-deflexus* *Phyllograptus* sp. *Trigonograptus*
	D4	*Cardiograptus morsus* .. *Oncograptus* sp.	*Didymograptus caduceus* *D. v-deflexus* *Tetragraptus serra* (Brongniart) *Trigonograptus*
	D5–D4	*Oncograptus biangulatus* .. *O. upsilon* T. S. Hall	*Didymograptus caduceus* *D. caduceus* var. *manubriatus* T. S. Hall *D. v-deflexus* *Tetragraptus serra* *Dichograptus* sp.
	D5	*Oncograptus upsilon* (absence of *Cardiograptus*)	As for D5–D4 *Trigonograptus*
Castlemaine	C1	*D. caduceus* (maximum development) (absence of *Oncograptus*)	*Didymograptus caduceus* *D. caduceus* var. *manubriatus* *D. forcipiformis* Ruedemann *D. v-deflexus* *D.* cf. *uniformis* Elles and Wood *D. nitidus* (J. Hall) *Tetragraptus serra* *Goniograptus speciosus* T. S. Hall *Dichograptus* sp.

The succession in this locality is normal, and the zonal fossils have apparently the same range as in other Darriwilian areas. D5 with *Oncograptus upsilon* only is poorly represented, but this is probably due to the lack of exposure rather than to actual absence of deposition. Beds on the Ironbark Creek, about a mile from its source, containing an abundant fauna without *O. upsilon*, are C1 since *Didymograptus caduceus* is very abundant and not associated with *Oncograptus*. No evidence of the passage of these into D5 could be found on the Ironbark Creek, and the next beds observed contain *O. biangulatus*, in addition to *Oncograptus upsilon*. It seems likely, therefore, that *O. upsilon* appeared first, in accordance with the development of *Oncograptus* and *Cardiograptus* from *Didymograptus caduceus*, as worked out by Harris, to be joined later in passage beds between D5 and D4 by *Oncograptus biangulatus*. In these beds there is some difficulty in distinguishing the two species, since the gap between the two extreme forms, which are distinguished

by the difference in the angle of divergence of the uniserial stipes, is bridged by several intermediate forms with mean values of that angle. These observations are confirmed by Harris (personal communication), but he has not so far found the two species in association. This record therefore requires confirmation in other localities. The passage beds in all localities are succeeded by normal D4 in which *Oncograptus biangulatus* and *Cardiograptus morsus* are associated, though *C. morsus* is rather rare until D3 is reached. There *O. biangulatus* is completely replaced by *Cardiograptus*.

The passage from D3 to D2 has not been observed owing to insufficient exposure. The fauna of D2 is very distinctive, *Diplograptus austrodentatus* occurring to the exclusion of most other forms. *Didymograptus caduceus* is rare and *Glossograptus* sp. is occasionally found.

Details of Sections.

The axial lines shown on the map and section (Pl. XX.) are based on exposures in:—

1. The Ironbark Creek.
2. Sloss's Gully.
3. The Ballan-Bacchus Marsh road.
   The cuttings along the Ballarat-Melbourne railway.
4. Creek C.
5. Creek B.
6. The Werribee River.

Creek B and Creek C are two of the western tributaries of the Werribee, unnamed on the maps of the district, and so lettered for convenience of reference.

These features give a more or less E.-W. section across the area, and are so placed that they cover almost the whole of it. The correlation of the black slate bands in any two adjacent sections is made difficult by the varying pitch of the folds. The prevailing pitch is to the north as is shown by the variation in the strike, but exceptions in which a pronounced southerly pitch is developed are not rare. Longitudinal sections would probably show the type of structure already proved to exist at Bendigo ([6] and [7]) where the "pitch lines" show undulations rather than a persistent slope.

Few observations have been made close to the adamellite owing to lack of exposure, the nearest being on the railway, in Sloss's Gully and in a tributary of the Ironbark Creek. In the railway cutting, the strikes are similar to those in other parts of the area, and the fold axes maintain their original direction until the contact is reached. An anticline less than 5 chains from the contact

shows a decided northerly pitch, so that adamellite probably reached its present position by magmatic stoping rather than by forcible intrusion. Similarly in the other localities, 10 or 12 chains from the contact, the observed dips show no deflection of the axial lines.

1. Ironbark Creek.

The black slates exposed along this creek are fossiliferous only in the western part, i.e., within the metamorphic aureole of the adamellite. The bands in the extreme west (1 3) yield—

Didymograptus caduceus Salter (large and abundant).
D. nitidus (J. Hall).
D. cf. uniformis E. and W.
Tetragraptus sp.
Dichograptus sp.

This assemblage is correlated with a well preserved fauna obtained further east at I 6, containing—

D. caduceus Salter.
D. caduceus var. manubriatus T. S. Hall.
D. nitidus (J. Hall).
D. cf. uniformis E. and W.
D. forcipiformis Rued.
Tetragraptus serra (Brongn.).
T. cf. quadribrachiatus (J. Hall).
Goniograptus speciosus T. S. Hall.
Dichograptus sp.
(?) Diplograptus sp.

These beds are C1.

Slightly to the east of I 3, and in a syncline, occur beds (1 1) containing *Oncograptus biangulatus, Didymograptus caduceus, D. v-deflexus, Phyllograptus* sp., and *Tetragraptus serra.* The horizon of these is D4. They fail to repeat on the other limb of the syncline, and are replaced by black slates (1 5) with *Oncograptus biangulatus, O. upsilon, Didymograptus caduceus, Tetragraptus* sp., and *Trigonograptus* sp., which are probably passage beds between D4 and D5. Since the thickness of beds separating C1 and normal D4 does not accord with the thickness of D5, observed in other parts of the area, and the beds belonging to D5-D4 do not occur on both limbs of the syncline, it is inferred that trough-faulting has taken place, this cutting out on the west limb the beds corresponding to I 5 and reducing the apparent thickness between D5 and D4.

The other black slate outcrops marked are either unfossiliferous or contain poorly preserved examples of *Didymograptus caduceus* and crustaceae, so that on this section no further evidence as to structure, beyond that given by observation of dip and strike, is available.

2. Sloss's Gully.

Exposures are few, and black slates outcrop only in the head of the gully, the eastern outcrops being mainly sandstones. The beds at S2 contain *Didymograptus caduceus, Dichograptus* sp. (abundant) and *Tetragraptus quadribrachiatus,* and are tentatively placed in C1. They are succeeded in a syncline about 2 chains to the west by black slates (S1 and S3) with *Oncograptus biangulatus, Didymograptus caduceus, Tetragraptus serra* and *T. quadribrachiatus.* I 2 is probably the same bed which is repeated in an anticline still further west.

The exposures in the eastern part of Sloss's Gully, while unfossiliferous, are of use in confirming the axial lines set up on the evidence of sections along the road, railway and Creek C.

3. Ballan-Bacchus Marsh Road and Melbourne-Ballarat Railway.

Fossiliferous black slates are common along this section, and show the presence of D5, D4, and D3, as well as of the passage beds between D5 and D4. D4 is the most extensively outcropping zone owing to the repetition by folding of a small thickness of slates. Going east from RD9 (D5), with a fauna containing—

Didymograptus caduceus Salter
D. caduceus var. manubriatus T. S. Hall
D. v-deflexus Harris
Phyllograptus sp.
Oncograptus upsilon T. S. Hall,

a gradual passage upwards is observable, beds belonging to D3 occurring at RD5, about $\frac{1}{4}$ mile to the east. The ascent is not continuous, however, as numerous minor puckers bring beds belonging to D5 to the surface for some distance east of RD9. At the quarry near the 42-mile post on the railway (RL2) and at RD6 a fauna including—

Didymograptus caduceus Salter
Oncograptus biangulatus H. and K.
Cardiograptus morsus H. and K.
Tetragraptus serra (Brongn.)
T. quadribrachiatus (J. Hall)
Phyllograptus sp.
Goniograptus sp.
Trigonograptus sp.
Lasiograptus sp.,

places the beds in D4. The graptolites, though plentiful, are not very well preserved, since the slates are weathered and have been further metamorphosed by the intrusion of an acid dyke

along the axis of the anticline. At RD5 *Cardiograptus morsus* is associated with *Didymograptus caduceus, D. v-deflexus* and *Phyllograptus* sp. East of this locality the black slates contain only poorly preserved examples of *Didymograptus caduceus, D. v-deflexus* and *Phyllograptus* sp. and are repeated by a number of small acute folds that pitch towards the south.

Going west from RD9, where the highly cleaved, horizontal black slates are at the axis of an anticline, the next fossiliferous slates are passage beds between D5 and D4, as shown by the association of *Oncograptus upsilon* and *O. biangulatus*. These are repeated, RD10 and RD11 being the same band, by a minor fold on the western limb of the anticline at RD9. The remainder of the section is made up of closely folded beds belonging to D4. Two faults were observed in the railway cutting near the 42½-mile post, but the displacement of the beds does not appear to have been very great. *Oncograptus biangulatus* is plentiful in the slates on the road west of RD11, but is not common in the railway cuttings, where the slates seem more indurated. West of RL7 *Didymograptus caduceus* was the only form found, but the bands can be connected with the corresponding slates in the road. The contact of the adamellite and the Lower Ordovician occurs at the western end of the railway cutting, about 12 chains from the last fossiliferous black slates on Creek C near the railway. The intervening bands are fossiliferous at the head of Sloss's Gully, and serve to connect this section with the outcrops along the Ironbark Creek.

4. Creek C.

The western localities (W9 and W10) yield *Didymograptus caduceus* only, and the age of the beds is thus uncertain, though by comparison with those in the railway cutting, they are probably D4. At W12 and W13, on the north flowing tributary of Creek C rising at the railway bridge, *Oncograptus biangulatus* and (?) *Cardiograptus* were obtained, and the beds were thus to be correlated with those in the small quarry on the road west of the bridge (RD6A). The next fossiliferous band is about ¼ mile to the east of W13, on a north-flowing tributary rising at Gatehouse 24, and the occurrence of small Diplograpti and of *Didymograptus caduceus* shows these beds to belong to D2. The slates here are of the same type as those of the Werribee Gorge. The next outcrop to the west, at the head of a small south-flowing tributary, is unfossiliferous, but the slates are of the same lithological type as the Lower Darriwilian of the road and railway cuttings, Ironbark Creek, &c. The boundary D3–D2 is therefore placed with some hesitation between these two outcrops.

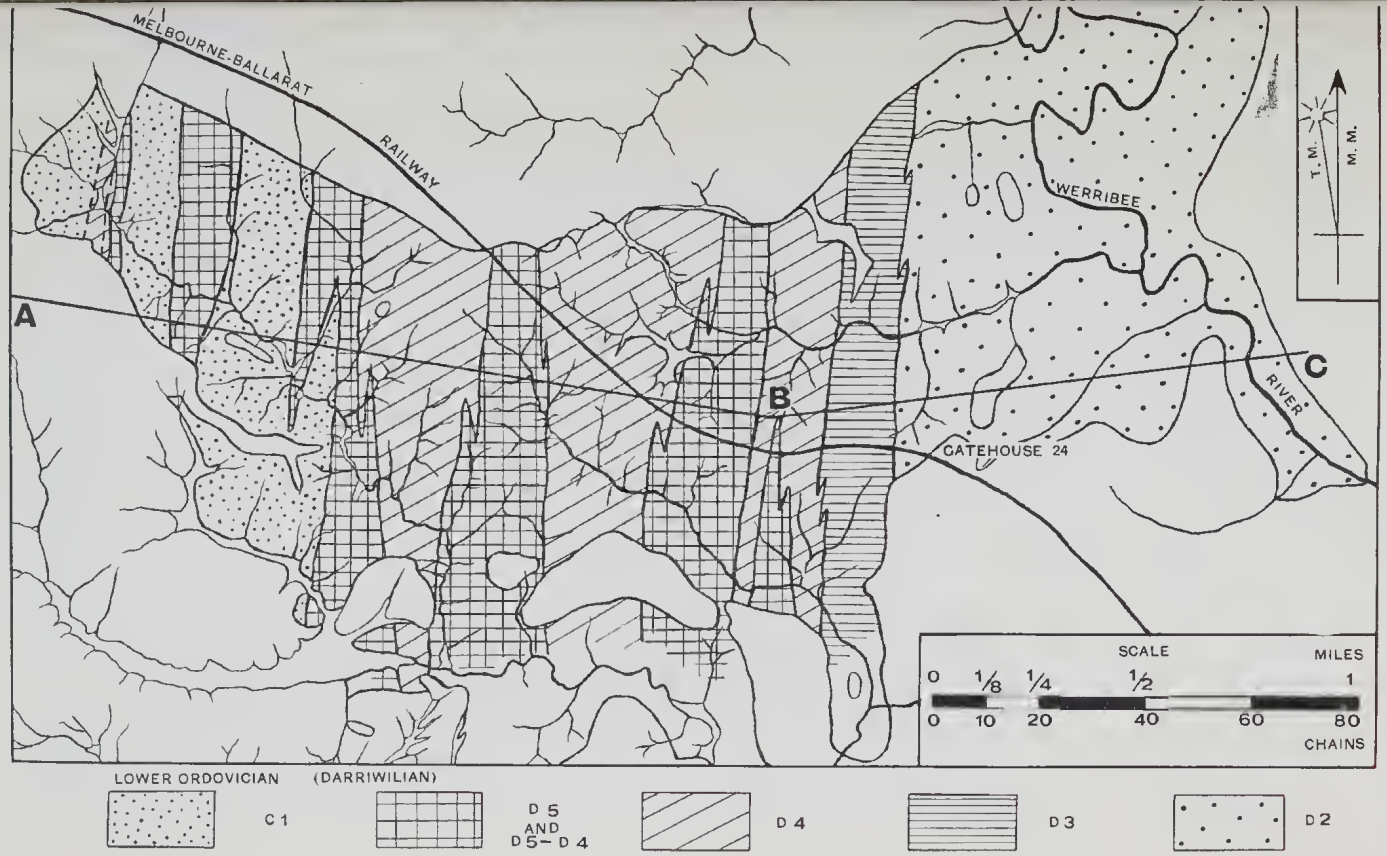

MELBOURNE-BALLARAT
RAILWAY
WERRIBEE
T. M.
M. M.
A
B
C
RIVER
CATEHOUSE 24
SCALE
MILES
0 1/8 1/4 1/2 1
0 10 20 40 60 80
CHAINS
LOWER ORDOVICIAN (DARRIWILIAN)
C 1
D 5 AND D5–D 4
D 4
D 3
D 2

FIG. 1.

18891.—4

5. Creek B.

Though black slate bands are numerous, graptolites are rare and not well preserved. The only fossiliferous locality, where small Diplograpti were obtained, is about 5 chains from the Werribee River. The unfossiliferous slates are correlated with corresponding bands in the graptolite-bearing slates in Creek C to the north, and additional evidence for the axial lines, crossing the valleys of the Werribee River and Creek C, was obtained.

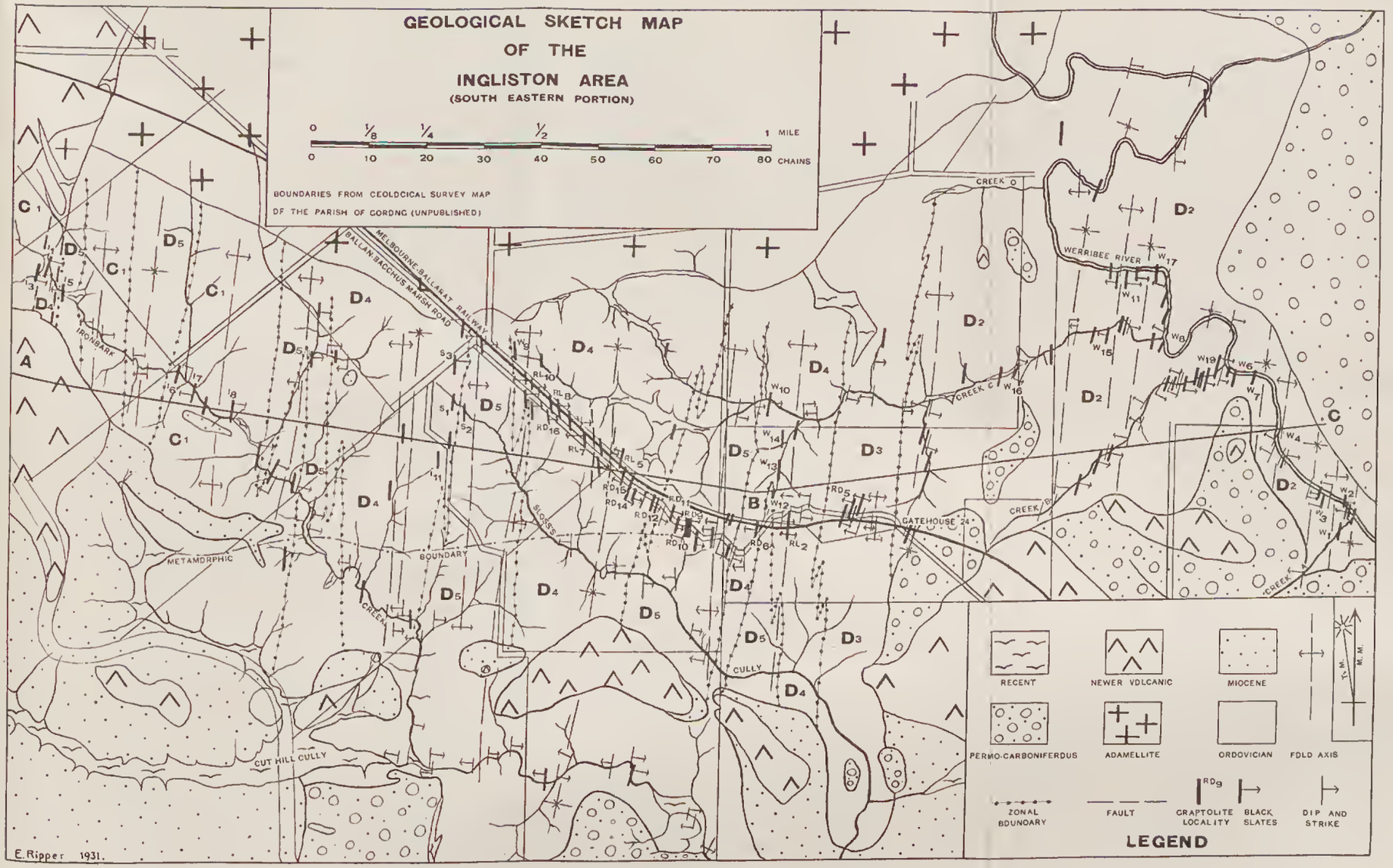
6. Werribee River.

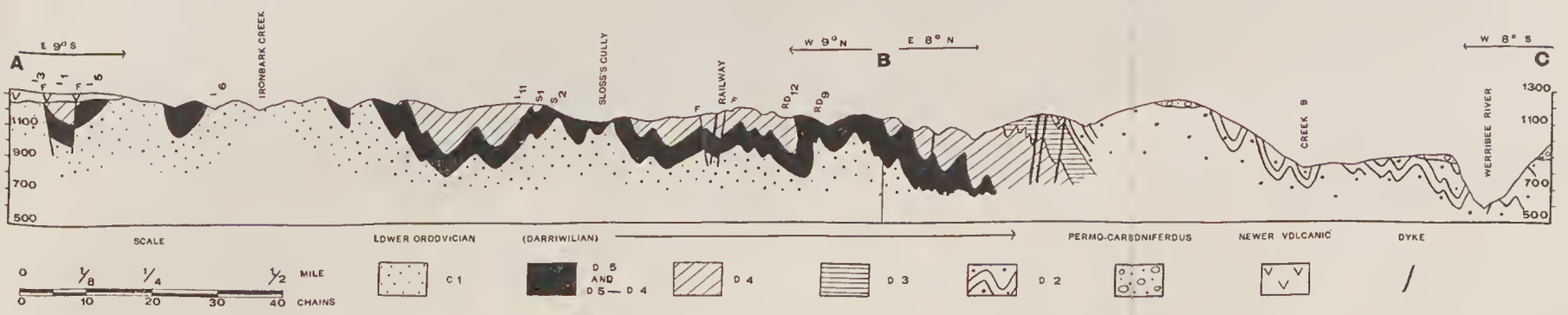
Much of the information on which the axial lines in this part of the area are based was obtained from an unpublished map by Mr. C. C. Brittlebank. Graptolites are fairly abundant, the best preserved faunas occurring south-east of Pyramid Rock, at W3 and W4. The beds belong to D2, *Diplograptus austrodentatus* being very common, and associated with *Glossograptus* sp., *Didymograptus caduceus*, and *Tetragraptus* sp. As the river is followed northwards, graptolites are more difficult to obtain as the slates become more metamorphosed. The slates north of Creek D are unfossiliferous. As none of the assemblages contain *Oncograptus* or *Cardiograptus*, they are probably all D2. No graptolites belonging to D1, e.g., *Didymograptus nodosus*, *Climacograptus*, or large Diplograpti, have been obtained.

Conclusion and Acknowledgments.

The Ordovician of the area comprises the uppermost zone of the Castlemaine series (C1) and the whole of the Darriwil series except D1. The distribution of the zones is shown in Fig. 1. The oldest bed occurs in the western part of the area, along the Ironbark Creek, and passes up into D5 and D4 in the railway and road cuttings. Still further east *Cardiograptus* appears, but these D3 beds are not well exposed along any of the lines of section. A higher zone (D2) outcrops in the Werribee Gorge and in the valleys of its western tributaries, but the passage from D3 to D2 has not been observed. The area is, therefore, the western limb of a syncline, of which the axis is unknown, since few observations east of the Werribee are possible owing to the presence of the Permo-Carboniferous tillite. The ascent from D5 to D2 is not continuous, as the beds are very closely folded, and older beds are frequently brought to the surface by minor anticlines.

In conclusion, I wish to thank Mr. R. A. Keble for drawing attention to the area, Mr. W. Baragwanath for allowing me to use the map on which Pl. XX is based, and Mr. C. C. Brittlebank for the use of his unpublished map of the Werribee Gorge area. I should like also to thank Mr. W. J. Harris for many valuable suggestions and help in identifying the graptolites, and Dr. Summers for his assistance throughout the year.


GEOLOGICAL SKETCH MAP
OF THE
INGLISTON AREA
(SOUTH EASTERN PORTION)
0 1/8 1/4 1/2 1 MILE
0 10 20 30 40 50 60 70 80 CHAINS
BOUNDARIES FROM GEOLOGICAL SURVEY MAP
OF THE PARISH OF GORDNG (UNPUBLISHED)
MELBOURNE-BALLARAT RAILWAY
BALLAN-BACCHUS MARSH ROAD
IRONBARK
METAMORPHIC BOUNDARY
CUT HILL CULLY
SLOSS'S CULLY
GATEHOUSE
WERRIBEE RIVER
CREEK C
CREEK B
CREEK
RECENT
NEWER VOLCANIC
MIOCENE
PERMO-CARBONIFERDUS
ADAMELLITE
ORDOVICIAN
FOLD AXIS
ZONAL BOUNDARY
FAULT
GRAPTOLITE LOCALITY
BLACK SLATES
DIP AND STRIKE
LEGEND
E. Ripper 1931.


A
B
C
E 9° S
W 9° N
E 8° N
W 8° S
IRONBARK CREEK
SLOSS'S CULLY
RAILWAY
CREEK B
WERRIBEE RIVER
1300
1100
900
700
500
SCALE
0 1/8 1/4 1/2 MILE
0 10 20 30 40 CHAINS
LOWER ORDOVICIAN (DARRIWILIAN)
PERMO-CARBONIFERDUS
NEWER VOLCANIC
DYKE
C1
D5 AND D5—D4
D4
D3
D2

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